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On Some Observations of Solar and Terrestrial Phenomena by Subionospheric Transmitted Signals

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Abstract. Continuous monitoring of VLF/LF sferics and subionospheric transmitted signals are being continued over Agartala (Lat 23 ° N, Long 91 ° 24′ E), North-Eastern part of India, since 1975. From the recording of one such subionospheric signal at 40 kHz from Japan (Lat 36 ° 11′ N, Long 139 ° 51′ E), some observed typical variations in the transmitted signal amplitude during solar flares and meteor showers will be presented in this paper. The effects of perturbation in the lower ionosphere due to solar flare and occurrence of Leonid meteor showers upon subionospheric signal at 16.3 kHz transmitted from VTX1 Indian Navy station located at Vijayananarayanam (Lat 8 ° 25′59.88″ N, Long 77 ° 48′ E), have been detected over Kolkata (Lat 22 ° 34′ N, Long 88 ° 30′ E). Some results of observations will also be exhibited here.

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1 Introduction

Different terrestrial phenomena, like solar X-ray flares, solar proton events, solar cycle changes, meteor showers, geomagnetic storms, seismo-associated strong electromagnetic waves, global thunderstorm and lightning, Schumann resonance and others, while entering the earth's atmosphere produce EM radiations due to their interaction with the medium, which propagate and reach the surface of the earth [1-18]. The emitted EM radiation is found to have frequency range from a few Hz to 300 kHz (ULF to LF).

The vast electric fields from any of these sources introduce anomalous and significant perturbations in both the received phase and amplitude of subionospheric signals during their propagation through such disturbed region [1,7-10,20-22]. The large electric field penetrates down to D-region height and markedly increases the ionization rate causing the increase of electron density through the ionization of neutral constituents in the medium [19]. By this way, ion composition, temperature and other physical parameters within the ionosphere are perturbed at different levels of altitude extending from the lowest D-region to the magnetosphere height.

Solar flare and solar cycle induced lower ionospheric changes have been investigated from amplitude and phase measurement of subionospheric VLF transmitted signals [2,3,6,7,23].

The majority of the effects of solar wind variability exhibit themselves through geomagnetic storms, magnetospheric substorms and changes of geomagnetic activity. Geomagnetic storms are believed to cause the largest global geomagnetic effects among other phenomena. The lower part of the ionosphere responds very sharply to geomagnetic storms thereby affecting considerably VLF propagation in the earth-ionosphere waveguide [24]. Mid-latitude ionospheric D-region perturbations introduced during major geomagnetic storms are being measured through VLF amplitude variations along several signal paths in both the northern and southern hemispheres [12].

It has been found that during major geomagnetic activity, the fluctuations in amplitude persist several hours after the occurrence of storms [12]. The frequency content of those fluctuations as well as the location of timing and distances are examined by using multiple VLF signal paths and auroral activity patterns based on auroral flux measurement obtained through the NOAA-POES satellites. Their observations are consistent with the NOAA-POES satellite data. The subionospheric VLF signals thus can be used as a diagnostic of high energy auroral precipitation at mid-latitudes during disturbed geomagnetic conditions. The characterization of auroral precipitation can increase the understanding of the mechanisms and ionospheric effects of massive geomagnetic storms.

The investigations about the understanding of lightning discharges and other associated processes which introduce modulations in the earth-ionosphere waveguide causing variations in the received phase and amplitude of subionospheric signals are being continued over the last two decades. Various works include the exploration and interpretation of high-altitude dominated processes connected with thunderstorms [20,25,26]. These include VLF sprites produced by red sprites discharges stretched over the altitude ranging from 50–80 km, QE-field produced early Trimpi due to relatively large disturbed regions, lightning – EMP produced Elves at about 80–90 km altitudes that produce staggered changes in the subionospheric VLF/LF signals. The observed VLF perturbations are responsible for the differences in the ionospheric modifications of electron temperatures and ionization structure due to lightning discharges and thunderstorms. Short impulses of strong electromagnetic signals from lightning discharges in the neutral atmosphere on entering the plasma regions of the atmosphere propagate through the anisotropic ionosphere medium. These produce whistlers in ULF/LF frequency range [27].

The electromagnetic impulses excited during ground to cloud lightning discharges exhibited the effects of guided wave and of the dispersive ionospheric plasma along their paths. The effect of such subionospheric propagation on whistlers has been recorded by French DEMETER LEO satellite. Some new signal structures consisted of enormous fractional-hop whistlers were identified, which are known as spiky whistlers (SpW). In recent years, the generation and propagation characteristics of the recorded SpW signals have been modeled and interpreted successfully [28, 29].

In the presence of geomagnetic field and different types of irregularities, the medium within the earth-ionosphere waveguide exhibits inhomogeneous and anisotropic dielectric properties. The effects of anomalous electric field during solar and different geophysical events introduce more complexity in the medium properties which significantly affects subionospheric propagation of transmitted signals in the VLF/LF range below 300 kHz. Based on FDTD computational solutions of Maxwell's equations, the modulation upon subionospheric wave propagation due to the effect of such localized ionospheric perturbation are being successfully analyzed [30-32].

Quite a good number of papers have been published on ionospheric perturbations associated with earthquakes through the use of subionospheric VLF/LF propagation [14,22,33-35]. This method of measurement is highly advantageous because any earthquake near the great-circle path from the transmitter to the receiver can influence the VLF propagation characteristics. From the VLF/LF data, the seismo-ionospheric perturbations are investigated through the statistical studies on the correlation between ionospheric perturbations and seismic activity [36,37], and also through the case studies for selected large earthquakes from which the detailed investigation of seismo-ionospheric perturbations associated with recent huge earthquakes can be made [16,38-40]. For clear understanding of seismo-ionospheric perturbations (characteristics, structure, dynamics and generation mechanism), both the methods are to be applied simultaneously.

Anomalous effects in Schumann resonance phenomena are known to be associated with large earthquakes having a magnitude greater than 6.0. The anomaly is characterized mainly by the unusual increase in amplitude of the fourth Schumann resonance mode along with a significant frequency shift of its peak frequency ($\sim$1.0 Hz) from its conventional value. In the case of Chi-Chi earthquake in 1999 at Taiwan, the anomaly appeared from about one week to a few days before the main shock [16]. For earthquakes of small amplitude, the anomaly appears one day before and lasts until one day after the main shock. The Schumann resonance is a natural global electromagnetic phenomenon mainly in the tropical region excited by lightning discharges. The anomalous behaviour of the Schumann resonance that observed in Japan is found to be associated with the Chi-Chi earthquake at Taiwan. The discussion and interpretation of the generation mechanism have been beautifully presented in this work [16].

Some typical effects on amplitude of Japanese subionospheric transmitted signal at 40 kHz due to solar flares and meteor showers will be presented in this paper. These are the outcome of the recorded data at Agartala (Lat 23° N, Long 91° 24$'$ E), North-Eastern region of India, at different periods over the past twenty years. Moreover, some effects on the Indian Navy VTX1 16.3 kHz VLF signal amplitude during solar X-ray bursts on November 23, 2004 and Leonid meteor showers on November 19, 2004, recorded over Kolkata (Lat 22° 34$'$ N, Long 88° 30$'$ E) will also be reported here.

2 Observational Results of 40 kHz Sub-Ionospheric Signal from Agartala

2.1 Some Aspects of 40 kHz Signal

Location Japan

Latitude 36° 11$'$ N

Longitude 139° 51$'$ E

Transmitting antenna

Type Omni-directional

Power at radiation 10 kW

Operation Continuous

Transmitter call sign JG2AS/JJF-2

2.2 Instrumentation

The receiver system mainly consists of (a) Antenna (b) AC amplifier (c) Selective circuit (d) Detective circuit (e) Logarithmic amplifier, and (f) Recording device. The effective height of antenna is fixed to 8.63 m and the terminal capacitance of the antenna wire is kept at 694 pF. The experimental set-up installed at Agartala, Tripura, consists of a loop antenna to receive vertically polarized electric field of the electromagnetic signal. The recording system consists of loop antenna feeding a number of OP-AMPs used in tuned radio frequency mode. The output of the AC amplifier is detected and the DC level is further amplified logarithmically. The DC gain has been used to adjust the receiver's sensitivity corresponding to the incoming signal which shows marked variation over the year. The DC output is used as the signature of the amplitude of 40 kHz signal. The overall gain of the amplifier is 120 dB with a band width of 200 Hz. The time constant of the recorder is 7.5 s. A Gyrator-II type VLF receiver has also been made useful for recoding this signal [41]. Using computer sound card, data were recorded at a sample rate of 10/s which have been analyzed through origin 5.0. The block diagram for VLF/LF recording system is depicted in Figure 1.

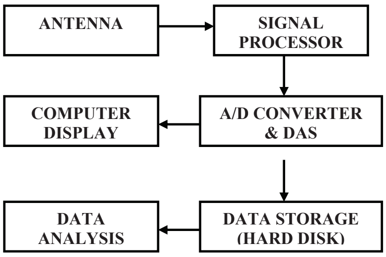

Figure 1. Block diagram of VLF/LF recording system.

3 Sub-Ionospheric Signals Recorded from Agartala

3.1 VLF/LF recording

Under normal condition, the amplitude of 40 kHz signal shows sunrise minima, recovery effect, afternoon maxima and sunset minima, respectively. During the presence of any externally triggered vast source, large effects are pronounced in the amplitude and phase of the transmitted signal. The outcome in the records of some of the sources will be presented now.

3.2 Solar flare

Solar flares cause significant perturbations in the received VLF/LF signals propagating in the Earth-ionosphere wave-guide [19]. The intense radiations from solar flares when travel towards the earth, there will be enhancement of D-region ionization [2,3]. For this, the subionospheric transmitted signals are greatly affected. Stratospheric electric fields get modified due to conductivity enhancements caused by the energetic particles during solar flares [42]. Figure 2 shows a typical enhancement in signal strength due to solar flare in 40 kHz occurred

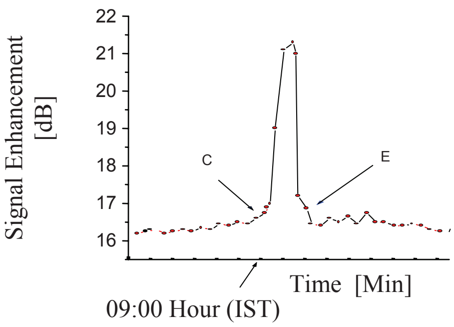

Figure 2. Typical enhancement in signal strength due to solar flare.

during 0854 Hour to 0916 Hour on January 24, 2007. Here, C, the commencement time and E is the end of the event.

During solar flare, the signal level rises and follows the sequences of enhanced solar radiation. This has been termed as Sudden Enhancement in Signal Strength (SES). A small in number of SES will be briefly discussed now.

3.3 Few observed SES

Occurrences of SES in different solar phases P1, P2, P3 and P4 and their relationship with different types of X-ray flares:

P1: The Sun moves from Tropic of Cancer to Equator (21 Jun-21 Sep)
P2: The Sun moves from Equator to Tropic of Capricorn (22 Sep-21 Dec)
P3: The Sun moves from Tropic of Capricorn to Equator (22 Dec-21 Mar)
P4: The Sun moves from Equator to Tropic of Cancer (22 Mar-21 Jun)

Solar cycle	Solar phase	Percentage association of SES with X-ray flares of types		
		Impulsive	GRF	Spikes
	P1	81	85	65
	P2	78	81	62
22^{nd}	P3	72	78	58
	P4	68	75	56
	P1	79	79	61
	P2	74	76	57
23^{rd}	P3	68	72	54
	P4	65	68	51

Some correlation studies are depicted in Figure 3.

The results show good correlation with solar cycle variations. But the magnitudes are solar cycle dependent. It is seen that the effects are slightly higher in 21^{st}–22^{nd} solar cycle than in 22^{nd}–23^{rd} solar cycle.

4 Solar Cycles

Solar cycles are shown in Figure 4.

Monthly smoothed sunspot number	21: Large dashed line curve 22: Small dashed line curve 23: Solid line curve
Actual monthly sunspot number	21: 22: 23: Shown by the corresponding dotted curve

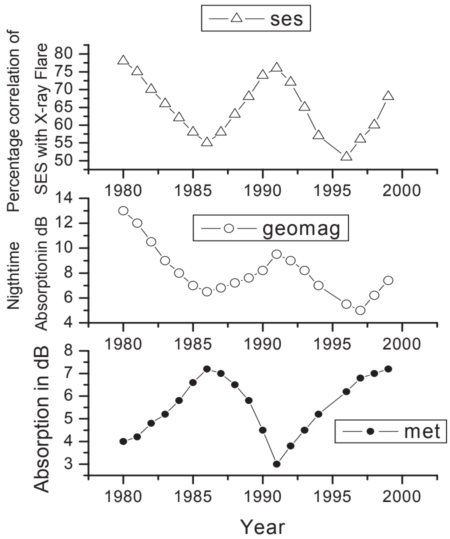

Figure 3. Three graphs show the percentage correlation of SES, average nighttime absorption in geomagnetically active days and average absorption in sporadic meteorically active days in various years of 21st-22nd, 22nd-23rd solar cycles.

- Cycle 21 started in June 1976 and lasted 10 years and 3 months.
- Cycle 22 started in September 1986 and lasted 9 years and 8 months.
- Cycle 23 started in May 1996.

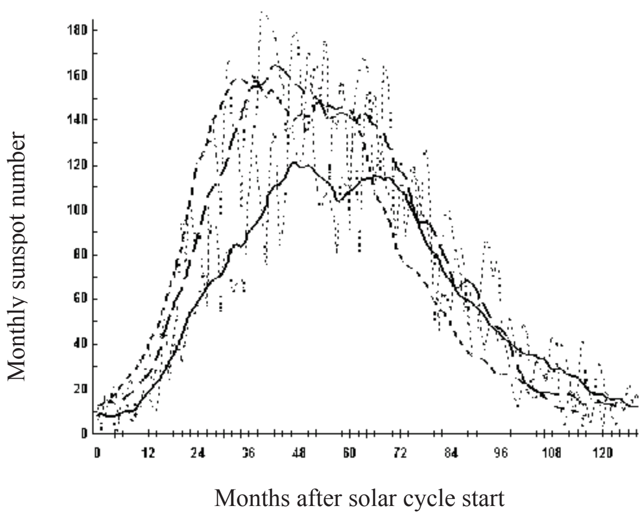

Figure 4. Different solar cycles.

The sunspot numbers during solar cycles are the representative points of the absorption of 40 kHz signal.

5 Leonid Meteor Showers

The Leonid meteor showers of 1998 have been presented in Figure 5 by recording its effects on 40 kHz Japanese subionspheric signal over Agartala. The shower exhibited peak activities on November 16, 1998. At 40 kHz signal frequency, the influences of atmospherics were relatively much lower compared to lower frequencies. The signal strength is sufficiently strong for detection over Agartala (Lat 23 ° N, Long 91 ° 24′ E) having 4884 km great circle distance.

The day from November 15 to 21, 1998 had very clear sky and no serious 'thunder-bolt' related events were reported at Agartala. So apart from the solar terrestrial influences on the ionosphere, the period was ideal for observing meteor showers. Moreover, no solar flare events were reported around the period of occurrence by GOES10 and GOES12 satellites which continuously monitor solar activity. At the predicted peak activity period, there were no local lightning or flare generated perturbations in the ionosphere that could alter the average signal received at Agartala.

The extra ionization produced by the supersonic meteoroids during their passage through lower ionosphere was the cause of high enhancement of signal level, which is about eight to nine times the normal value.

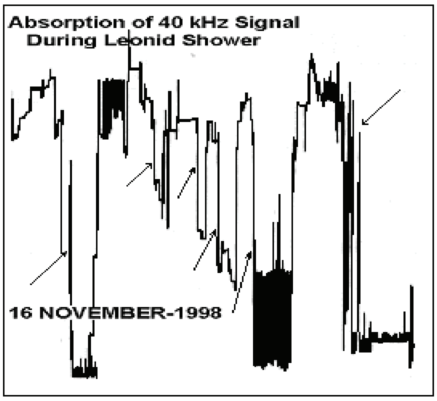

Figure 5. Typical Leonid meteor shower of 16 November, 1998.

6 Observational Results of 16.3 kHz Sub-Ionospheric Signal from Kolkata

6.1 Specific features of 16.3 kHz signal

Location Vijayananarayanam

Latitude 8 ° 25′59.88″ N

Longitude 77 ° 48′ E

Transmitting antenna

Type Omni-directional

Power at radiation 4 kW

Operation Continuous

Transmitter call sign DL4BBL

To receive the VLF signal, a horizontal 8 SWG straight copper wire of length 120 m was installed as an antenna at a height of 20 m from ground. To record the signal, a Gyrator-II type VLF receiver was fabricated. The block diagram of the recording system is given in Figure 1. The VLF receiver was tuned at 16.3 kHz with a quality factor around 250. The overall gain of the amplifier is around 40 dB. The rms value of the signal was recorded using a Pentium IV computer sound card at a sample rate of 10/s. The recorded data were analyzed later using Origin 5.0.

6.2 Solar flare

From continuous recording of transmitted VLF signal VTX1 at 16.3 kHz transmitted from one of the Indian Navy stations at Vijayanarayanam (Lat 8°25′59.88″ N, Long 77°48′ E), a solar flare is observed at Kolkata on November 23, 2004, through its effect on the propagation of the transmitted VLF signal. The signal strength is sufficiently strong for detection at Kolkata having 1981 km great circle distance. The commencement of flare time matches nearly with the time recorded by GOES12 satellites both in long and short X-ray range. The total duration of the flare was around 45 min. The effect of the flare on the ionosphere was very strong, which modified the reflection coefficient of the ionosphere in the VLF range. Figure 6 summarizes the results.

6.3 Leonid meteor showers

The days from November 14 to 20, 2004 had very clear sky and no serious ‘thunder-bolt’ related events were reported at Kolkata [43]. So apart from the solar-terrestrial influences on the ionosphere, the period was ideal for observing

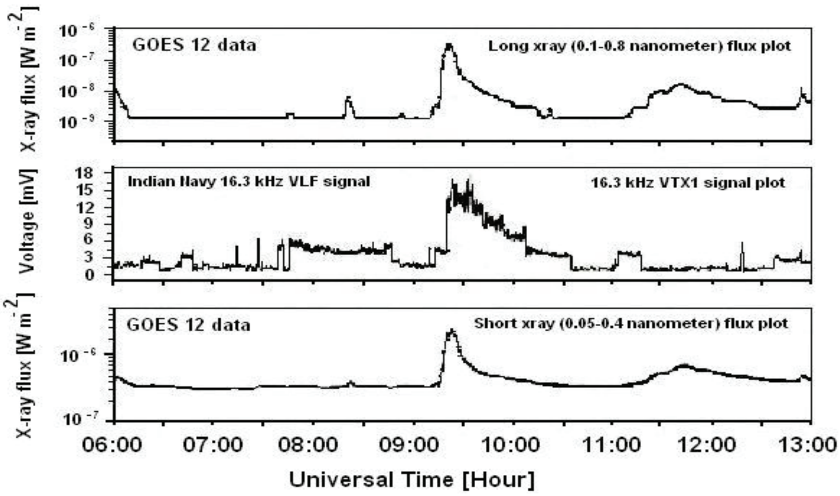

Figure 6. Indian Navy VTX1 16.3 kHz VLF signal amplitude along with NOAA GOES12 satellite data during solar X-ray flares occurred on November 23, 2004 are shown.

meteor showers. Moreover, no solar flare events were reported around the time by GOES 10 and GOES 12 satellites that continuously monitor solar activity [44]. At the predicted peak activity period, there were no local lightning or flare generated perturbations in the ionosphere which could alter the average signal received at Kolkata.

Several occurrences of meteor showers were detected. Figure 7 shows the effects of Leonid meteor showers on VLF signal on November 19, 2004. The signal level increased six to seven times the normal value. The extra ionization produced by the supersonic meteoroids during their passage through lower ionosphere must be the cause of this enhancement. The successive events in the showers were so dense that the individual events could not be resolved, since the resolution of the measurement system was not sufficient. Other showers were not so strong as on November 19, 2004.

During the entry of the Leonid into the earth's atmosphere, there will be strong fluctuation of charge distribution in the medium which enhances the rate at which the energy gets randomized. As a result, instability is produced. For this, the relative electron-ion drift velocity may exceed the value for the onset of Kelvin-Helmholtz instability. The compressible ionospheric plasma driven by velocity shears and earth's magnetic field at the frontal path of the meteor increases the growth rate of Kelvin-Helmholtz instability thereby generating electromagnetic waves that produce the observed effects in the subionospheric signal.

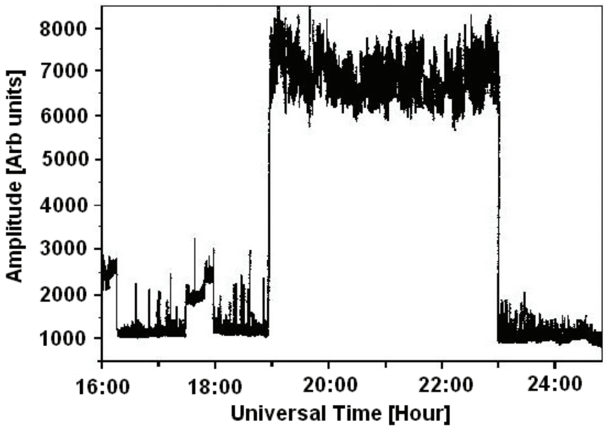

Figure 7. Leonid meteor shower on November 19, 2004.

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